A NOVEL AC-AMPLIFIER FOR ELECTROPHYSIOLOGY: ACTIVE DC SUPPRESSION WITH DIFFERENTIAL TO DIFFERENTIAL AMPLIFIER IN THE FEEDBACK-LOOP

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Abstract - **A novel AC amplifier for electrophysiological measurements that uses three op-amps based instrumentation amplifier (IA), and active suppression of the input offset was designed. The development followed the requirements to increase the common mode rejection ratio, thereby allow the recordings of physiological signals in a noisy environment. In the proposed circuit the high common-mode rejection ratio was achieved by using a high gain at the first stage of the IA (60 dB) and no passive components at the inputs. The feedback was achieved by means of a differential to differential amplifier placed in the input loop. This configuration provides an active suppression of DC-offset by feeding back an integrated form of the output that is equal to the input, yet of the opposite sign. The SPICE simulation of the novel amplifier with a gain of 80 dB and a high-pass cutoff frequency at 100 mHz are presented in this paper.**

Keywords **– AC-amplifier, electrophysiological signals, CMRR, DC offset suppression**

I. INTRODUCTION

Electrophysiological signals are very important for diagnosing the functioning of peripheral nerves, muscles, cortical activity, and heart functioning. The interface between the biological source of signals and an electrophysiological recorder are electrodes and preamplifier. The quality of these two elements is essential for reproducible and precise measurements. The signals to be recorded are very small compared to the noise caused by the environment (e.g., power line interference), the base line is frequently unstable, different artifacts are often very large [1, 2]. Therefore, a preamplifier has to have high Common Mode Rejection Ratio (CMRR > 110 dB), flat gain in the frequency range from at least 100 mHz to 5kHz, high differential input impedance, and selectable gain from 80 dB to 120 dB. The amplifier should use low power components, and occupy small PCB area, if it is to be used within portable systems.

The three op-amps based IA provides the required high-gain input stage. In order to avoid saturation due to high amplification of contact potentials arising at electrode-electrolyte interfaces an AC coupling is essential [3]. This can be achieved with the passive elements by, for example: 1) placing a series capacitor with the gain setting resistor of the full differential input amplifier; 2) placing coupling capacitor directly at the amplifier's inputs [4]; 3) using bootstrapped buffer which provides both AC coupling and high input impedance [3]; and 4) placing an audio transformer at the amplifiers input [5]. All these AC coupling configurations can cause a degradation of CMRR and noise characteristics of the circuit [6, 7]. In addition, passive DC suppression techniques often require impractical high-valued passive components.

Most of the above problems can be resolved by using an active DC suppression technique. The two op-amp configurations and monolithic instrumentation amplifiers based on the current feedback principle [e.g., 6] provide active DC suppression using the integrated version of the output. In the realization of electrophysiological amplifiers with such an active DC suppression the general difficulty arises how to subtract the input (sum of the differential voltage and the DC-offset) from the integrated version of the output. The summation of these two signals must be done without degrading the amplifiers' balanced structure and its CMRR. A possibly good solution to this problem [7] is to place a true floating voltage controlled voltage source in the input of the IA opposite to the DC-input offset source. This floating source was realized as an anti-parallel configuration of two general-purpose optocouplers.

We propose a solution where the DC offset artifact is minimized by implementing a feedback signal being equal to the input DC offset, yet of the opposite sign by means of an Analog Devices AD8138 differential to differential amplifier. We developed and simulated the AC-amplifier that could eventually be used for recordings of ECG, EEG, EMG, ENG, and other electrophysiological signals within virtual and telemedicine instruments [8].

II. PROPOSED CIRCUIT

Active DC-suppression of the offset in a three op-amps based instrumentation amplifier can be achieved with an arrangement presented in Fig. 1.

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The amplifier output V_o is given by:

$$V_o = \left(V_{in} - K_f \frac{V_o}{s} \right) \cdot A_{Do} \qquad (1)$$

where A_{Do} denotes the gain of the instrumentation amplifier, K_f is the feedback loop gain and V_{in} is the input differential voltage. The transfer function $A_D(s)$ has the form:

$$A_D(s) = \frac{V_o}{V_{in}} = \frac{A_{Do} \cdot s}{(s + K_f \cdot A_{Do})} \qquad (2)$$

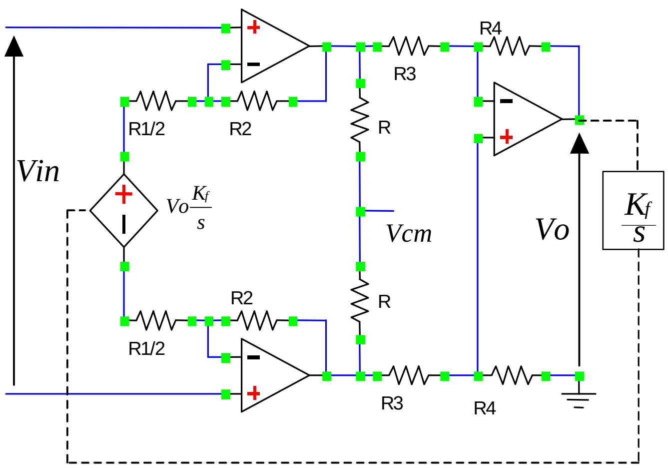

Fig. 1: Principle of active DC suppression

The high-pass cutoff frequency is:

$$fc = \frac{K_f}{2\pi} A_{Do} \qquad (3)$$

The voltage source in the IA's input loop opposite to the DC-input offset source does not need to be "truly" floating. Instead of a true floating source, it is satisfactory to provide differential signal with common mode level equal to common mode voltage of the input signal. A differential to differential amplifier (e.g., Analog Devices AD8138) is a suitable circuitry for generating the appropriate feedback signal. The AD8138 can be used as single-ended to differential or differential to differential amplifier. On the +out and –out pins the circuit outputs signals that matches the amplitude, yet is phase shifted for 180 degrees. The output common mode voltage is adjustable via the pin Vocm, and it is equal to the voltage applied to the Vocm pin.

Considering the given functional description of AD8138, we applied an integrator output signal at single-ended input of the AD8138 and input common mode signal Vcm at the Vocm of the AD8138. The AD8138 will give, on its differential output, a differential signal proportional to the integrated output, with the common mode level equal to common mode voltage of the input signal. Fig. 2 shows the circuit diagram of proposed AC amplifier. For the testing purposes, an amplifier with gain of 80dB and high-pass cutoff frequency of 0.1Hz was designed.

According to the equations (1) to (3) and scheme shown in Fig. 2, feedback gain K_f is given as the following product of three terms:

$$K_f = K_R K_i K_{AD}. \qquad (4)$$

The term K_R is an attenuation of the integrator's input voltage (voltage divider R11-R12), second term K_i is integration gain and K_{AD} is a differential gain of the AD8138 amplifier. The differential gain K_{AD} is defined as:

$$K_{AD} = R_f / R_g \qquad (5)$$

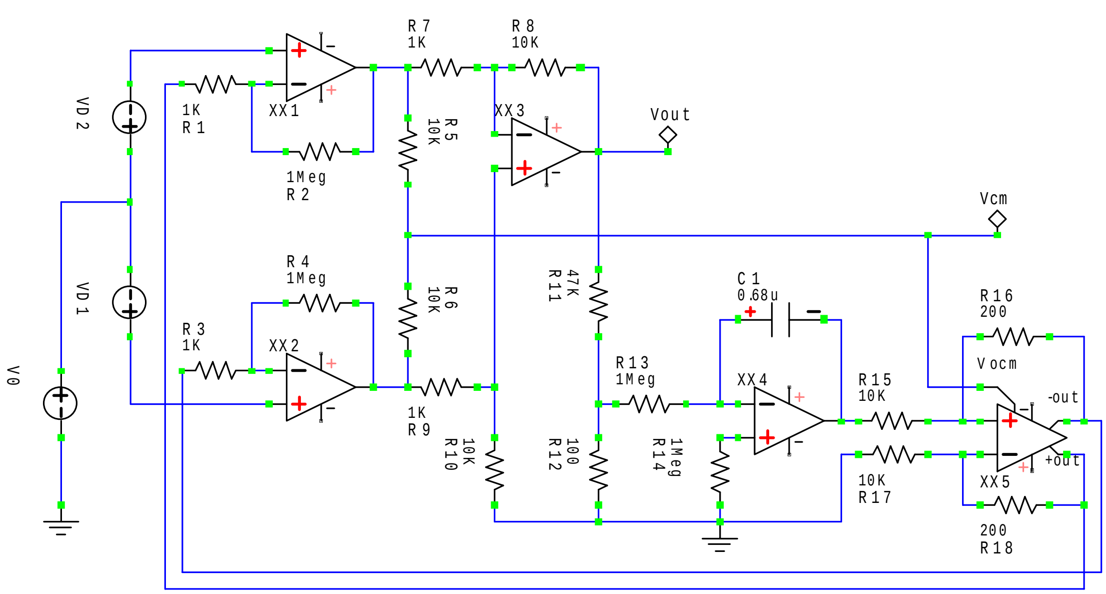

Fig. 2: The scheme of the novel AC amplifier

where R_f=R$_{16}$=R$_{18}$ and R_g=R$_{15}$=R$_{17}$. Thus, equation for the high-pass cutoff frequency (3) become:

$$fc = \frac{Ki \cdot K_R \cdot K_{AD}}{2\pi} ADo \qquad (6)$$

The maximum offset input voltage that can be suppressed is given as a product of the maximum output voltage of the integrator and the gain K_{AD}. It is of interest to have a constant gain K_f, yet increase the gain K_{AD}. Ultimately, two other feedback gain values have to be appropriately decreased. The resistive attenuator before the integrator was used in order to obtain desired DC suppression range with practically acceptable values of R_{13} and C_1.

III. Simulation Results

For testing purposes SPICE simulation of circuit shown in Fig. 2 was performed. The three op-amps IA was modeled by using Linear Technology's SPICE macro-model of op-amp OP27C. An integrator is based on Linear Technology's

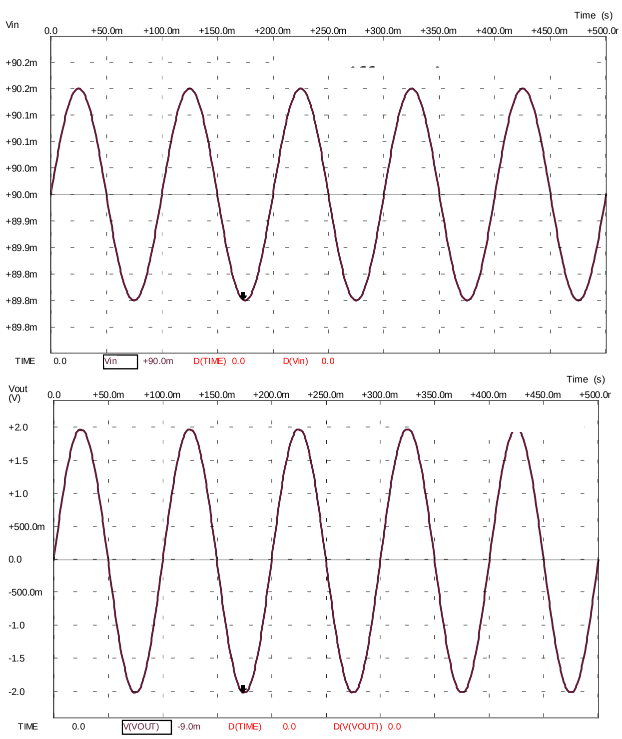

Fig. 3: The input (top panel): f= 10 Hz, u = 0.2 mV, U_{offset} = 90 mV, u_{CM} = 3 V @ 50 Hz. The SPICE simulated output signal is shown at the bottom panel. The gain of the IA is 80 dB.

SPICE macro-model of op-amp LTC1049, and AD8138 is simulated with Analog Devices SPICE macro-model. Power supply of the circuit was ±5 V. Simulation was done with differential mode input signal shown in the top panel of Fig. 3 (frequency of 10 Hz, amplitude of 0.2 mV, and DC-offset of 90 mV), and added 50Hz common mode signal amplitude 3 V.

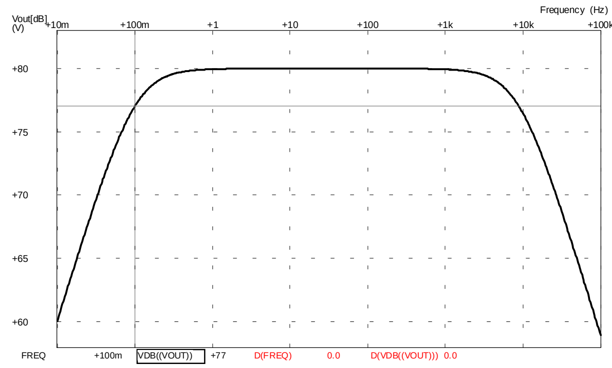

Fig. 4: Frequency characteristic of differential mode gain

Output signal, result of transient SPICE simulation, is shown in Fig. 3 (bottom panel). AC component of differential input signal is amplified with gain of 80 dB.

Frequency characteristic of differential gain is presented in Fig. 4. The differential gain is 80 dB, high-pass cutoff frequency is 0.1 Hz, and bandwidth is more than 8 kHz.

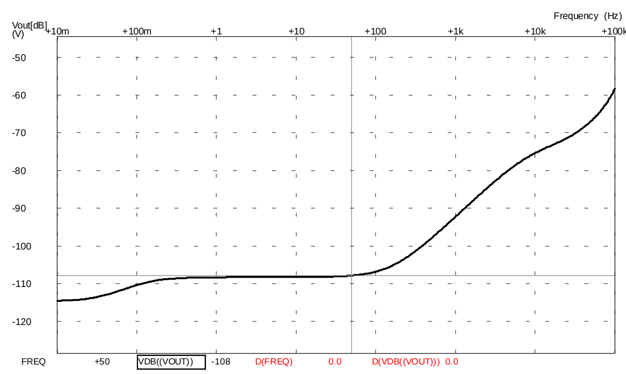

Fig. 5: Frequency characteristic of the common mode gain

Frequency characteristic of common mode gain is shown in Fig. 5. At 50 Hz common mode attenuation is 108dB, and with differential mode gain of 80 dB gives theoretical value CMRR of 188 dB.

IV. Conclusions

An electrophysiological amplifier with active DC-suppression was designed. This amplifier provides AC coupling from the first stage without degrading CMRR, input impedance or noise characteristics. It provides a high gain integrated into a single stage, avoiding saturation problems due to electrode offset voltages.

The presented circuit is based on the idea that the floating voltage controlled source is placed in the input loop of the IA. This voltage source suppresses DC input offset because it is added to the input, and it has equal amplitude, yet the opposite sign. In order to emulate this floating source, a low cost, differential to differential AD8138 amplifier with a separate pin for the adjustment of the common mode level of the output signal was introduced. Thus, the proposed circuitry is a feasible element, which guaranties active DC suppression, and eliminates problems with the passive DC suppression [6, 7]. In this configuration a floating point source is realized with one standard, linear, easy to use IC component being simpler for application compared to e.g. a method where the optocouplers with experimentally obtained characteristics have to be employed [7].

With its flexible three part structure of the feedback loop (an resistive attenuator, integrator and AD8138), the circuit provides simple way for obtaining desired cut-off frequency, and DC suppression range with the practically acceptable, low valued passive components.

Here, we presented results of the electrophysiological amplifier's SPICE simulation with a gain of 80 dB, a cutoff frequency of 100 mHz, and DC-input range of ±90 mV. All passive components have standard values and integrator capacitance of only 0.68 μF is used. With these characteristics and its high bandwidth of approximately 8KHz, this amplifier can be used in recordings of ECG, EMG, EEG and other electrophysiological signals. These performances were obtained with the ±5 V power supply, which makes this circuit suitable for battery supplied mobile systems.

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